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for

POSITION SENSING SYSTEM

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POSITION SENSING SYSTEM

FIELD OF THE INVENTION

[0001] The present invention relates to a position sensing system. More particularly, the present invention relates to a passive optical position sensor. More particularly, the present invention relates to an optical sensor for determining the position of a mechanical device. More particularly, the present invention relates to a fiber optic position sensor for determining the physical position of a flight control surface of an aircraft.

BACKGROUND OF THE INVENTION

[0002] It is generally known to provide a position sensor, such as for an aircraft. Such conventional position sensors provide signals representative of the physical position of a "flight control surface" of the aircraft. An exemplary flight control surface includes an aileron used to control rolling and banking movements of the aircraft. Such conventional position sensors are typically located outside the main body or pressure envelope of the aircraft. Hence, such conventional position sensors (e.g. located on the wings of the aircraft) are subject to extreme environmental stress including electrical phenomena such as lightning and high intensity radiated fields ("HIRF"), as well as temperature, vibration, moisture, dirt, etc. Such conventional position sensors have several disadvantages including that they are intrinsically analog (i.e. include an electrical circuit having an output that is proportional to the input) and are adversely affected by electrical noise interference.

[0003] Accordingly, there is a need for a position sensor that is mechanically and electrically robust. There is also a need for a position sensor that is relatively precise. There is also a need for a position sensor that is electrically passive and resists signal degradation. There is also a need for a

position sensor that provides in digital form a signal representative of a physical position of a flight control surface of the aircraft. Yet further, there is a need for a position sensing system having one or more of these or other advantageous features.

SUMMARY OF THE INVENTION

[0004] One embodiment of the invention relates to a passive sensing system for determining a physical position of a mechanical device. The sensing system comprises an encoding system configured to convert a position signal representative of the physical position of the mechanical device into an encoded signal in a binary format. The sensing system also comprises a plurality of secondary optical paths coupled to a primary optical path, each positioned between a light source and the encoding system. The encoded signal comprises a plurality of pulses of light each sequentially delayed by the secondary optical paths.

[0005] Yet another exemplary embodiment of the invention relates to a system for determining a physical position of a flight control surface of an aircraft. The system comprises means for transmitting an incident pulse of light. The system also comprises means for dividing the incident pulse of light into a plurality of incident pulses of light. The system also comprises means for reflecting the incident pulses of light and for providing a plurality of reflected pulses of light. The system also comprises means for delaying the incident pulses of light and for delaying the reflected pulses of light. The system also comprises means for detecting the reflected pulses of light. A signal encoded in a binary format and representative of the physical position of the flight control surface is provided to the means for detecting the reflected pulses of light.

[0006] Still another exemplary embodiment of the invention relates to a method for determining a physical position of a flight control surface

of an aircraft. The method comprises transmitting an incident pulse of light from a light source through a primary optical path and subsequently dividing the incident pulse of light into a plurality of incident pulses of light. The method also comprises transmitting the incident pulses of light through a plurality of secondary optical paths. The method also comprises reflecting the incident pulses of light with a reflector. The method also comprises transmitting the reflected pulses of light through the plurality of optical paths and subsequently transmitting the reflected pulses of light through the secondary path. The method also comprises detecting the reflected pulses of light with a control system having a photodetector. An encoded signal representative of the physical position of the flight control surface is read by the control system.

[0007] Another exemplary embodiment of the invention relates to a passive sensing system for determining a physical position of a flight control surface of an aircraft. The sensing system comprises an encoding system configured to provide a signal encoded in a binary format and representative of the physical position of the flight control surface. The sensing system also comprises a single fiber optic cable having a first diameter and coupled between a light source and the encoding system. The sensing system also comprises a plurality of fiber optic cables each having a second diameter less than the first diameter and configured for coupling to an end of the single fiber optic cable. An illumination pulse from the light source is divided into a plurality of pulses by the plurality of fiber optic cables.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Exemplary embodiments will hereafter be described with reference to the accompanying drawings, wherein like numerals denote like elements, and:

[0009] FIGURE 1 is a schematic block diagram of a sensing system for determining a physical position of a flight control surface of an aircraft according to an exemplary embodiment;

[0010] FIGURE 2 is a flow diagram of a method for providing a signal representative of the physical position of the flight control surface using the sensing system of FIGURE 1 according to an exemplary embodiment;

[0011] FIGURE 3 is a block diagram of the sensing system of FIGURE 1 according to an alternative embodiment;

[0012] FIGURE 4 is a flow diagram of a process of the sensing system of FIGURE 1 according to an exemplary embodiment;

[0013] FIGURE 5 is schematic diagram of an encoding system of the sensing system of FIGURE 1 according to an exemplary embodiment;

[0014] FIGURE 6 is a flow diagram of a process of the sensing system of FIGURE 1 according to an alternative embodiment;

[0015] FIGURE 7 is a block diagram of the sensing system of FIGURE 1 according to an alternative embodiment;

[0016] FIGURE 8 is a schematic diagram of the encoding system of the sensing system of FIGURE 7;

[0017] FIGURE 9 is a schematic diagram of the sensing system of FIGURE 7;

[0018] FIGURES 10A through 10E are graphs of signals of the sensing system of FIGURE 7 according to exemplary embodiments; and

[0019] FIGURE 11 is a schematic diagram of the sensing system of FIGURE 7 according to an alternative embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EXEMPLARY EMBODIMENTS

[0020] Referring to FIGURE 1, a sensing system 20 having a position sensing system 60a is shown according to an exemplary embodiment. The sensing system is useful for detecting the physical position of mechanical devices in high power and high electrical noise environments (e.g. industrial controls applications where large motors, induction furnaces, etc. may be present, control rods in nuclear reactors, the thickness of rollers in steel mills, etc.). As shown in FIGURE 1, sensing system 60a is adapted to provide an encoded signal representative of a physical position of a flight control surface 16 of an aircraft 10 (shown as an aileron 18 of a wing 14).

[0021] Position sensing system 60a is located outboard or outside a main body or pressure envelope 12 of aircraft 10 as shown in FIGURE 1 according to a preferred embodiment. An optical encoding system 70 of sensing system 20 is configured to encode the signal representative of the physical position of flight control surface 16 into a binary format for reading by a control system 22. This is generally accomplished by splitting an incident or illuminating beam or pulse of light into a series of time-delayed optically encoded pulses communicated in serial fashion on a single fiber according to a preferred embodiment.

[0022] Referring further to FIGURE 1, control system 22 is shown located inboard or inside pressure envelope 12 according to a preferred embodiment. Input signals 26 are provided to control system 22 by other aircraft systems 58 (such as a control system of the aircraft) or are otherwise acquired by a user interface 24. Control system 22 runs programs, subprograms, routines and/or subroutines using input signals 26 to provide output signals 28. Output signals 28 are intended to control the position of flight control surface 16 according to a preferred embodiment.

[0023] Referring further to FIGURE 1 and to FIGURE 2, sensing system 20 includes a signal input system 30. Signal input system 30 provides to position sensing system 60a a query or input signal (shown in FIGURE 10A as an incident beam or pulse of light 54) from a lighting system 32 (step 102). Incident pulse of light 54 is communicated to position sensing system 60a via a communication system 40 (step 104). Incident pulse of light 54 is received by position sensing system 60a, which provides a reflected output signal (shown in FIGURE 10B as a reflected beam or pulse of light 56) that is encoded into a binary format according to a preferred embodiment.

[0024] Communication system 40 provides at least two functions according to a preferred embodiment: (1) the separation or division of incident pulses of light into a plurality of incident pulses of light where the number of incident pulses of light corresponds to the precision of position sensing system; (2) the serial delay and/or retention of the incident pulses of light and the reflected pulses of light (e.g. each by successive periods of about 4 nanoseconds) which provides for serial separation of the bits of the encoded signal for reading by the control system.

[0025] Referring further to FIGURES 1 and 2, reflected pulses of light 56 are encoded into binary format by encoding system 70 (step 108).

Reflected pulses of light 56 (e.g. a digitally encoded output position signal) are communicated to a signal output system 90 via signal communication system 40 (step 110). Signal output system 90 then provides the encoded position signal to control system 22. Control system 22 reads the encoded position signal, runs routines on the encoded position signal, and provides output signals 28 intended to control the physical position of flight control surface 16 (step 112) according to a preferred embodiment. According to an alternative embodiment, the control system may provide an output signal (e.g. to a display) representative of the physical position of the flight control surface or some other related parameter.

[0026] Referring to FIGURE 3, sensing system 20 is shown according to an alternative embodiment. Lighting system 32 of signal input system 30 is shown as a light emitting diode (LED) 34. The lighting system may include any light source that provides an incident beam or pulse of light such as a semiconductor laser diode according to alternative embodiments.

[0027] Referring further to FIGURE 3, LED 34 provides the incident pulse of light which travels in an optical path through communication system 40 in an input direction to position sensing system 60a. The incident pulse of light is sent back by optical encoding system 70 (having a series of reflectors 76 and absorbers 78) of a position sensor 62. The resulting reflected pulses of light travel through communication system 40 in an output direction to a photodetector 92 of signal output system 90.

[0028] Referring further to FIGURE 3, the reflected pulses of light are detected by photodetector 92 of signal output system 90. Photodetector 92 then provides to control system 22 a signal representative of the position of encoding system 70 and/or of the position of the reflectors and the absorbers (and of the position of flight control surface 16). According to a preferred embodiment, the position sensing system is “passive” (i.e. does not require

external electrical power) since it uses optical inputs and outputs (i.e. light transmission through very fine, flexible glass or plastic fibers). According to a preferred embodiment, the optical paths comprise elongate fiber optic cables made of a non-conductor such as glass or plastic.

[0029] Referring to FIGURE 4, a process 100 for determining the physical position of the flight control surface (based on the position of the reflectors and absorbers of the encoding system) is shown according to an exemplary embodiment. As shown in FIGURE 4, the signal input or incident pulse of light is provided to the position sensing system (i.e. the position and/or configuration of the reflectors and the absorbers of the encoding system is queried) (step 102). The incident pulse of light is turned back by the encoding system (i.e. an encoded output position signal) (step 112).

[0030] The encoding system is in a first predetermined position p_i or in a second predetermined position p_{i+1} depending on the position of the flight control surface (see steps 114 and 116 shown in FIGURE 2) according to an exemplary embodiment. For example, when the flight control surface is in a first position (e.g. aileron positioned at an angle of about 5.000 degrees) then the encoding system is in first predetermined position p_i -- and when the flight control surface is in a second position (e.g. aileron positioned at an angle of about 5.005 degrees) the encoding system is in second predetermined position p_{i+1}.

[0031] The reflected pulses of light comprise an encoded output position signal (see step 112). The encoded position signal comprises a "word" or binary number having bits corresponding to the number of "tracks" or data values of the encoding system (see e.g. FIGURE 5). For example, the encoding system shown in FIGURE 5 has two tracks which yield an encoded position signal having two bits (e.g. (track 1 value, track 2 value)).

[0032] The nature of the encoded position signal is then read by the control system (step 134). In general, if the control system identifies that the two-bit encoded position signal corresponds to a predetermined binary value (or "word"), then the control system makes a determination that the flight control surface is in a predetermined position. The control system may include a lookup table (e.g. that resides in memory or associated hardware) or a mathematical equation for correlating the binary value to a physical position of the flight control surface. The control system then provides an appropriate output signal (step 134).

[0033] Referring to FIGURE 5, encoding system 70 of position sensing system 60a is shown according to an exemplary embodiment. Encoding system 70 includes columns shown as a track 80a and a track 80b. The number of tracks corresponds to the number of data bits of the encoded position signal. Each of track 80a and track 80b include a row shown as a row 74a and a row 74b. Each of the rows corresponds to a position of the flight control surface (e.g. p_i, p_{i+1}, etc.). Each of the columns intersects a row at a quadrant shown as a cell 84a through cell 84d. Each of cells 84a through 84d are configured to transmit or reflect the incident pulses of light from communication system 40 (see reflector 76 in cell 84a) or are configured to absorb the incident pulses of light (see pass-through or absorber 78 in cells 84b, 84c and 84d).

[0034] The rows of reflectors and absorbers of the encoding system are repositioned or reconfigured (e.g. by mechanical actuation of a lever, shaft, etc.) according to the physical repositioning of the flight control surface according to a preferred embodiment (see steps 114 and 116 shown in FIGURE 2). Referring further to FIGURE 5, when the flight control surface is in the first physical position, the incident beams of light are reflected and/or absorbed by row 74a representative of position p_i. When encoding system 70 is in position p_i, cell 84a reflects the incident pulse of light and cell 84b absorbs the incident pulse

of light -- thus, a return binary value of (1,0) is encoded (i.e. value of track "a" of row "a", value of track "b" of row "a"). When the flight control surface is in the second physical position, the incident beams of light are reflected and/or absorbed by row 74b representative of position p_{i+1}. When encoding system 70 is in position p_{i+1}, cell 84c and cell 84d both absorb the incident pulses of light -- thus, a return binary value of (0,0) is encoded. The encoded outputs of the input query are "closed" (i.e. every query returns a result) according to a preferred embodiment.

[0035] Referring further to FIGURE 5 and to FIGURE 6, rows 74a and 74b of reflectors 76 and absorbers 78 are positioned (or reconfigured) among position p_i and position p_{i+1} according to the physical position (or repositioning) of the flight control surface (step 116). The incident pulse of light is provided through communication system 40 (i.e. input query signal) (step 102) and divided into a series of pulses. The incident pulses of light are sent back by reflectors 76 and absorbers 78 and return through communication system 40 (i.e. encoded output position signal) (step 106). The reflected pulses of light are encoded into binary format by encoding system 70 (see FIGURE 5). The encoded position signal is read by the control system, which provides an output signal representative of the position of the flight control surface (step 126).

[0036] Referring to FIGURE 7, sensing system 20 is shown according to an alternative embodiment. An application specific integrated circuit (ASIC) 98 of control system 22 is shown coupled to the lighting system shown as LED 34 according to a preferred embodiment. (According to an alternative embodiment, the ASIC may be separate and/or external from the control system.) Incident pulse of light 54 transmitted from LED 34 passes through a splitter 38. From splitter 38, incident pulse of light 54 passes through a primary communication optical path shown as a single fiber 46. A secondary optical path

shown as a fiber bundle 48 comprising individual fibers 50a through 50m abut against a terminal end of single fiber 46 in position sensing system 60a.

[0037] According to a particularly preferred embodiment, the single fiber may be relatively long having a length greater than about 10 km, preferably less than 1 km for non-aircraft applications, and a length of less than about 100 m for aircraft applications. Each of the individual fibers has a diameter less than the diameter of the single fiber according to a preferred embodiment. According to a particularly preferred embodiment, each of the individual fibers has a diameter of about 1/16 the diameter of the single fiber. According to an alternative embodiment, the diameter of the single fiber may be substantially the same as the diameters of the individual fibers of the bundle (e.g. coupled by an optical expanding device, optical spreader, star coupler, etc. to provide division of the incident pulse of light).

[0038] Each of individual fibers 50a through 50m have a delay section or loop 52 for delaying the time it takes the pulses of light to travel between position sensing system 60a and control system 22 according to a preferred embodiment as shown in FIGURE 7. In general, a single light pulse (e.g. incident pulse of light 54) is directed out of single fiber 46 and is divided by fiber bundle 48. The incident pulse of light is effectively divided into a series of time-separated pulses by the delay loops.

[0039] The time-separated pulses are then sent back by the reflectors of position sensing system 60a (shown in FIGURE 7 attached to flight control surface 16 by a mechanical linkage 94, such as a rod or shaft, according to an exemplary embodiment). The reflected pulses of light are then detected by photodetector 92. That signal (i.e. from the reflected pulses of light) is amplified by an amplifier 96 and subsequently provided to ASIC 98.

[0040] Referring to FIGURE 8, encoding system 70 is shown according to an alternative embodiment. As shown in FIGURE 8, individual fiber 50a has no delay loop according to a preferred embodiment. The time it takes for incident pulse of light 54 to travel from LED 34, through single fiber 46, through individual fiber 50a and to return to photodetector 92 is somewhat undefined due to the undefined length of single fiber 46. However, once that time is determined (e.g. by detection of the reflected light from fiber 50a) the time it takes for incident pulse of light 54 to travel and return through individual fibers 50b through 50m is predictable.

[0041] According to a preferred embodiment as shown in FIGURE 8, the time it takes for incident pulse of light 54 to travel from LED 34 to reflector 78 is increased by about 2 nanoseconds for each of individual fibers 50b through 50m, respectively (due to the length of delay loop 52). Likewise, the time it takes for reflected pulses of light 56 to return from the reflector 78 to the photodetector is increased by about 2 nanoseconds for each successive individual fiber 50b through 50m, respectively (due to the length of delay loop 52). Thus, once the signal from individual fiber 50a is received by the control system, it is expected that the reflected output signal from each of individual fibers 50b through 50m will be received about 4 nanoseconds later than its predecessor. The total time to encode "n" bits is ((n-1) x 4 nanoseconds), where "n" is the number of delaying fibers, according to a particularly preferred embodiment. See also FIGURE 9 showing sequential 4 nanosecond periods of delay in receipt of the reflected beams of light from each of the individual fibers.

[0042] Referring further to FIGURE 8, individual fiber 50b associated with track 72b has a length that is longer than individual fiber 50a associated with track 72a (e.g. due to the greater length of delay loop 52 of individual fiber 50b) according to a preferred embodiment. Thus, the reflected pulses of light from track 72b will reach the photodetector after the reflected

pulse of light from track 72. According to a preferred embodiment, the photodetector receives the reflected pulses of light from each of tracks 72b through 72m after it receives the reflected pulse of light from the immediate predecessor. (See FIGURE 9.)

[0043] Referring further to FIGURE 8, tracks 72a through 72m of encoding system 70 are each in communication with individual fibers 50a through 50m, respectively. The first track (e.g. track 72a) corresponds to a marker or "start" bit to indicate the beginning of the word comprising the following bits (e.g. the encoding bits of tracks 72b through 72e). The final track (e.g. track 72m) corresponds to another marker or "stop" bit to indicate the end of the word. Thus, 13 tracks (including 1 start track and 1 end track) correspond to 2^{11} or 2048 predetermined physical positions of the flight control surface. According to alternative embodiments, the number of tracks (and/or bits) can be increased to increase the precision of the sensing system.

[0044] According to a preferred embodiment, the control system associates the reflected pulses of light received during time sequenced periods as coming from the encoded tracks (e.g. the reflected pulse of light from track 72a is received by the photodetector before the reflected pulse of light from tracks 72b through 72m, each which have a delay loop having a length greater than its predecessor, respectively). See also FIGURE 9 showing no additional delay of the reflected pulse of light sequentially associated with track 72a, and correspondingly larger periods of delay with each of tracks 72b through 72m, so that the reflected pulses of light are received in series by the control system due to the increasing lengths of the delay loops.

[0045] The lengths of the fibers may be optimized to reduce signal degradation according to any preferred or alternative embodiments. According to a particularly preferred embodiment, each of the individual fibers of

the fiber bundle has a different length. The lengths of the individual fibers increase sequentially by about 0.42 meters to account for a light propagation delay of about 2 nanoseconds according to a particularly preferred embodiment -- and the difference in length between the longest fiber of the fiber bundle and the shortest fiber of the fiber bundles is about 5.04 m according to a particularly preferred embodiment.

[0046] As shown in FIGURES 7 and 8, each of the illumination pulses cause a complete sample and read of the encoded position of the sensor. The sensor tracks may be encoded using a "gray code," whereby only a single bit changes from one position to the next according to a preferred embodiment. With this coding method, position boundary ambiguities may be resolved to output a valid +/- ½ "LSB" or least significant bit position.

[0047] Referring to FIGURES 10A through 10E, graphs of input and output signals of sensing system 20 are shown according to exemplary embodiments. As shown in FIGURE 10A, the light source (e.g. LED 34 shown in FIGURE 7) transmits incident pulse of light 54 (see step 102 in FIGURE 2). The incident pulse of light is reflected (see step 106 in FIGURE 2). The reflected pulse of light is encoded into a binary value (see step 108 in FIGURE 2). These binary values are shown in FIGURE 10B as a positive value representative of the reflected light (and encoded as a value of "1") and a null value representative of the absorbed light (and encoded as a value of "0") according to a preferred embodiment.

[0048] The output signal provided by photodetector 92 is amplified by amplifier 96 (see FIGURE 7) as shown in FIGURE 10C. The amplified output signal is sampled at a high rate (e.g. less than about 2 nanoseconds -- corresponding to a pulse of about 2 nanoseconds for the reflected pulses of the tracks) as shown in FIGURE 10D according to a

particularly preferred embodiment. Thus, the reflected pulses of light are delayed by about 4 nanoseconds for each track (due to the length of the delay loop) according to a particularly preferred embodiment (see FIGURE 9). According to alternative embodiments, the output signal may be sampled at a slower rate.

[0049] As shown in FIGURE 10E, the signals sampled in FIGURE 10D are encoded as a series of data bits for each of the tracks (shown as a value of (1,0,1,1,0,1,0,1,1,0,1,1,1)) corresponding to tracks 72a through track 72m where track 72a provides the "start" bit and track 72m provides the "end" bit of the "word"). This encoded value is representative of a predetermined position of the flight control surface.

[0050] Referring to FIGURE 11, sensing system 20 is shown according to an alternative embodiment. As shown in FIGURE 11, sensing system 20 may comprise multiple position sensing systems shown as position sensing systems 60b, 60c and 60d each similar to position sensing system 60a. Thus, single fiber 46 with the single incident pulse of light may be used by each of position sensing systems 60a through 60d, each of which may be associated with a different (or the same) flight control surface according to alternative embodiments. The reflected pulses of light from position sensing system 60a arrive at the photodetector at a predetermined time (e.g. about 2 to 24 nanoseconds as shown in FIGURE 9) according to a preferred embodiment. The reflected pulses of light from each of position sensing systems 60b through 60d are delayed for longer periods (e.g. about 50 nanoseconds, about 100 nanoseconds, about 150 nanoseconds, respectively) due to the length of delay loop 52 according to a preferred embodiment as shown in FIGURE 11.

[0051] The incident and reflected pulses of light may be transmitted by any optical path according to alternative embodiments. The pulses of light may be delayed by other devices intended to time-separate the

pulses of light (e.g. Doppler shift). According to an alternative embodiment, the delay loop may comprise an optical delay structure similar to the type employed in a ring laser gyro of the type of analog or ring laser gyros model nos. GG1320AN and GG1320AN commercially available from Honeywell International Inc. of Morristown, New Jersey.

* * *

[0052] The control system (see e.g. control system 22 shown in FIGURE 1) of the sensing system may comprise a computing device, microprocessor, controller or programmable logic controller (PLC) for implementing a control program, and which provides output signals based on input signals provided by a user interface, sensor or that are otherwise acquired. Any suitable computing device of any type may be included in the information display system according to alternative embodiments. For example, computing devices of a type that may comprise a microprocessor, microcomputer or programmable digital processor, with associated software, operating systems and/or any other associated programs to implement the control program may be employed. The controller and its associated control program may be implemented in hardware, software or a combination thereof, or in a central program implemented in any of a variety of forms according to alternative embodiments.

* * *

[0053] It is understood that while the detailed descriptions, specific examples, material types, thicknesses, dimensions, and shapes discussed provide preferred exemplary embodiments of the present invention, the preferred exemplary embodiments are for the purpose of illustration only. For example, the sensing system may be used to identify the position of any device

(including but not limited to a flight control surface) and is not limited to use in association with aircraft and other vehicles. The method and the system of the present invention are not limited to the precise details and conditions disclosed. Various changes will be made to the details disclosed without departing from the scope of the invention, which is defined by the following claims.